



INEEL/CON-01-01596
PREPRINT

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July 28, 2002

2002 INCOSE Symposium

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Performing Trade Studies in the CERCLA¹ Environment

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Abstract

During almost any project, situations will arise that require project management and/or engineering personnel to make choices regarding project direction or product development. Often these choices are simply a part of the normal engineering development cycle (e.g., refinement or optimization of the product design). Frequently, on Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) and other similar projects, trade studies are initiated to address concerns or issues raised by stakeholders (e.g., EPA, local and state governments, local tribes, public). Where CERCLA projects, by definition, deal with releases or threatened releases of hazardous substances that may endanger public health or the environment, these trade studies must balance safety, risk and health issues, as well as cost and engineering viability. How these trade studies are carried out and documented/presented to the stakeholders involved can often be the difference between continued project progress and a “stalemate” leaving the project in limbo.

This document describes a basic trade study process, which has proved successful in addressing stakeholder concerns while at the same time balancing the desires of the various parties involved.

Introduction

In this document, experiences from several trade studies performed during the development and design of a complex radioactive/hazardous chemical waste excavation, retrieval, packaging and storage system will be used to illustrate successful trade study processes.

The development and design project involved a waste site, where radioactive and hazardous chemical waste had been buried for approximately 30 years. The site was originally excavated to basalt and backfilled with a layer of

soil before waste was placed in the pit. During its operation, drums and boxes of waste were generally dumped into the pit by truck or bulldozer and larger items were placed in the pit by crane. Once in the pit, items were covered with soil either on a daily or weekly basis depending on the procedures used at the time of disposal. Due to unfavorable weather conditions, the pit was flooded at least once during burial operations, which may have changed the distribution of some materials in the pit.

Given that the inventory and location of waste materials in the pit were uncertain, it was determined that subsurface exploration was needed to understand the conditions in the subsurface and to obtain data regarding the types of waste that would be encountered. After several safety concerns were addressed (e.g., release of radioactive contamination to the environment), approximately twenty probes were inserted into the retrieval area. It was under these initial conditions that the project to excavate, retrieve, package and store pit waste materials was to begin.

Engineering development proceeded using these initial conditions and a preliminary design (including both technical and cost elements) was assembled and presented to stakeholders. The trade studies discussed in this paper were initiated as the design was reviewed and continued to mature.

Events that Trigger Trade Studies

Myriad are the events that can trigger the need for a trade study. All of these events have at their core the need for additional information in order to make proper decisions. Trades are a natural part of the design process, as products are refined and optimized. They are performed almost automatically in the course of good engineering practice. Trades are often made to

¹ Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA), commonly known as Superfund, was enacted by Congress on December 11, 1980.

find a way to reduce costs or to simplify a product manufacturing process. In the CERCLA environment, as in other project environments, additional forces can drive the need for trade studies. These can include:

- Stakeholder concerns and/or issues, often associated with public safety and mitigating risks
- Stakeholder desires, which may expand the scope of a project (e.g., changing an excavation and remediation project into a science and technology development project) and increase the overall cost
- Identification and clarification of Data Quality Objective (DQO) ambiguities, which can drive what project approaches are taken
- Public perception of a project's approach and its impact on the community
- Competing options, some of which rely on state-of-the-art technologies for project success

Almost inevitably, cost will be a driving factor in all trades.

Trade studies offer a disciplined method for evaluating options associated with any of the above triggers and providing defensible rationale for the resulting decisions. The trade studies associated with the above mentioned project were initiated to address ambiguities in the project DQOs and to address stakeholder comments regarding the 90% draft Remedial Design / Remedial Action work plan.

Trade Study Process

The trade study process is straightforward and involves a number of steps, which seem to be "common sense," but which often are overlooked, glossed-over or omitted. This process includes the following steps:

1. Understand the problem or objective
2. Generate evaluation or decision criteria
3. Generate solution alternatives
4. Perform "killer" trades on alternatives, if needed
5. Evaluate the technical and cost portions of alternatives

Results from a trade study should provide the performer with the information needed to make a well-informed decision. In addition, if it is documented properly, it provides the performer with a defensible and traceable set of information to defend decisions that were made during the course of development. For one of the trade studies associated with this paper, the study

showed that implementing the stakeholder's desires was more costly than expected and that the benefit gained by proceeding with the recommendation did not outweigh the cost of implementation. The trade study documentation provided them with credible decision information, including cost, for defending this decision.

Understanding the Problem or Objective(s)

Before any other steps are taken a meaningful problem statement must be developed. Much like the mission statement for a project, a problem statement, which clearly defines the issue to be evaluated, must be in place for a successful trade to be made. As has been stated by many, "...if you don't have the right problem, you won't get the right answer." Included in the problem statement should be the requirements and constraints that are imposed on the study. Concurrence from all impacted stakeholders should then be sought. If at all possible, involve as many of these stakeholders as practical in defining the problem. Obtaining agreement can be one of the biggest challenges in a CERCLA project, as stakeholders are often philosophically far apart. Without concurrence, any conclusions resulting from the study can and will be questioned by those not in agreement with the initial problem statement, stalling the project.

For one of the trade studies performed on the project above, stakeholders felt that some of the data quality objectives (DQOs) associated with the project were sufficiently ambiguous that a trade study should be performed. This required that more specific DQOs be generated, which better defined the stakeholder's desired output from the project. The Environmental Protection Agency (EPA) 7-step process² was used to develop the new DQOs. While the 7-step process is not the subject of this paper, the steps to generate a DQO dovetail nicely with those steps followed in performing a trade study (i.e., state the problem, identify decisions, identify inputs, specify boundaries, define decision rules, specify error tolerances and optimize the design). The seventh step in the DQO process, "optimize the design," is often where trade studies are performed. For the trade study referred to in this

² U.S. Environmental Protection Agency. 1994. *Guidance for the Data Quality Objectives Process*. EPA/600/R-96/055, Office of Research and Development.

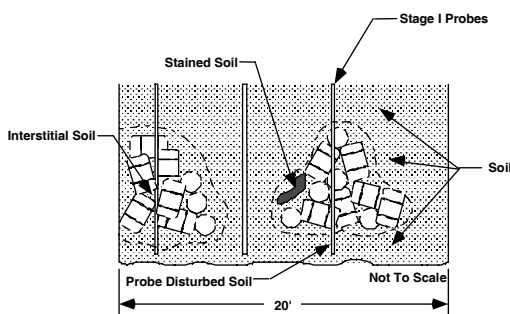
paper, the design problem statement that was generated as part of the DQO process was:

The Stage II Statement of Work and derived set of DQOs may need to be amended to more adequately support Stage III design decisions on how to retrieve and manage soils.

One of the resulting DQOs, which supported resolution of the problem statement was:

Determine the undisturbed in-situ transuranic (TRU) concentration and spatial distribution of the soils within the Stage II excavation area to support Stage III decision making.

A decision statement was identified, as were



decision inputs. Boundaries for the problem were specified (see Figure 1) and decision rules were defined. Once the decision rules were defined, error tolerances were specified for the problem. At this point, a formalized trade study was used to determine the optimal design solution to accomplish the objectives identified in the DQO process. This study was known as the Enhanced Soils TRU Characterization study, or Soils trade study for short.

Figure 1: DQO Boundaries

In a different trade study, the problem statement was a direct request from the customer, which asked for a *trade study to address agency comments with respect to detecting the TRU content of waste and soil*. This trade study assessed a variety of assay approaches, which could provide the desired detection level, while still meeting the other requirements imposed on the project.

In both instances, the focus of the trade study was understood either from the problem statement directly or, in the former case, from the newly developed DQOs. Likewise, in both cases, concurrence was received from the stakeholders involved before proceeding to the next step in the trade study process.

Evaluation Criteria

Depending on the complexity of the problem and/or the importance of the problem to the project, a trade study team should be assembled to perform the study (use a Graded Approach). Study team members should include subject matter experts (SMEs) with appropriate, applicable technical backgrounds to match the task (e.g., operations, environmental, industrial safety, fire protection, radiological control, engineering, and management). In addition, it is valuable to include individuals with multiple discipline backgrounds or generalists on the team who can look at the “whole” product or issue and provide input from a system perspective.

Before jumping to solution space, the team should select and set up the evaluation methodology to be used. This includes identifying and quantifying the criteria to be used in assessing and judging the potential solution alternatives. In the process of generating these criteria, the team should make sure they understand the problem and the priorities of their customer/stakeholders (e.g., performance, cost, schedule, health & safety and risk). A brainstorming session could be held, to list all of the criteria that the team felt were applicable to the study. Criteria should be directly linked to the customer / stakeholder needs and priorities. In addition, criteria should be as measurable and quantifiable, as possible, using known, easily understood units. This will help when presenting results to stakeholders, especially the public, when clarity and achieving understanding are critical. Criteria should also be tied to functional and performance requirements for the system. Simulation, experimental design, test data, etc. should be used wherever possible to minimize the need to rely on “engineering judgement,” as this is more subject to bias and error. During the Soils trade study the following potential criteria were brainstormed:

Table 1: Criteria Development, Brainstorming

Cost of acquisition
Cost, Life Cycle
Schedule
Error, TRU content
Resolution (TRU content, spatial distribution)
Separability (soil vs. waste)
Number of soil categories addressed
Safety and Health – worker exposure
Safety and Health – public
Safety and Health – environment
Technical maturity (design, development)
Schedule risk

Amount of in-situ disturbance
 Cross Contamination
 Versatility/flexibility
 Reliability, Availability, Maintainability (RAM)
 Complexity (operability)
 Decontaminability
 Secondary waste generation
 Complexity of sampling
 Number of samples required
 Impact on baseline design
 Stage II verification of Stage I

Definitions for all criteria should be documented and understood by all team members. Health & safety, risk, and regulatory compliance should almost always be included as criteria for CERCLA activities. An example definition for the Life-Cycle Cost criteria was “cost of the alternative being considered, including design, procurement, construction, operational readiness review, operations, D&D and disposal, as well as schedule variations.”

In addition to the definition, a figure of merit or measure should be documented for each criterion (for example, dollars for Life-Cycle Costs, or minimum resolution achieved in cubic feet for Spatial Distribution Resolution). In cases where no measure seems to exist for important criteria, define the criteria as explicitly as possible. The Soil trade study identified several criteria that did not have measurable parameters. In these cases, the definition included a qualitative figure of merit (for example, very complex design to simple design as a range for design complexity).

Care should be taken to evaluate the criteria to identify repetitive criterion. To be true to the study, criterion should be independent of one another. A trade study can easily become biased if multiple criteria are used that address the same basic factor or performance parameter. In the Soils trade study, the “Schedule” criteria was removed in that any change in schedule was reflected in the “Life-Cycle Cost” criteria. The consolidation process created a smaller set of differentiable criteria.

Criteria, which do not discriminate between alternatives, are of little use in a trade study and only burden the study team with more parameters to keep track of. The Soils trade study contained discriminating criteria, which included measurable (e.g., Life Cycle Cost, TRU Content Decision Error) and subjective (e.g.,

Technical Maturity, Flexibility, Intrusiveness) criteria.

In most trade studies, the criteria selected do not have equal value to the customer and stakeholders when it comes to making a decision regarding an alternative. Weights can be assigned to each criterion to appropriately scale the scores given for each alternative. The weighting of agreed upon criteria should also be accomplished before work is commenced on alternatives. All customers / stakeholders should provide concurrence to the set of criteria and their associated weights. In some cases obtaining agreement on these items can be difficult. During one of the trades studies performed on the retrieval system above, the stakeholders (i.e., contractor, customer, state government and EPA) agreed to use an average weight on each of the criteria. That is, each stakeholder submitted their weights for each criteria and an average weight was calculated.

Trade studies may also contain criteria known as “Threshold” criteria. These are criteria that must be met in order for the alternative to be considered at all. For CERCLA projects, regulatory compliance and health & safety issues are examples of threshold criteria. Depending on the circumstance, public perception of an alternative may be such that it should be considered a threshold criteria. Often, threshold criteria are selected to assist in reducing the number of alternatives to be evaluated in what are known as “killer” trades.

Various methods for evaluating alternatives against criteria exist. Two methods are described in this paper. In the first method, each alternative is scored separately against each of the criteria and a total score is calculated after applying the appropriate weights. This is a very simple and straightforward method, which is illustrated below:

Alternative #1

Criteria #1 Score * Criteria #1 Weight = Criteria #1 Total

Criteria #2 Score * Criteria #2 Weight = Criteria #2 Total

Criteria #3 Score * Criteria #3 Weight = Criteria #3 Total

Total Score for Alternative #1 = Criteria #1 Total + Criteria #2 Total + Criteria #3 Total

This would then be repeated for each alternative and criterion, so that “Total Scores” would be calculated for each alternative. A simple

spreadsheet could be used to perform the calculations.

Another method for evaluating alternatives is known as pair-wise comparison. This is accomplished by pairing each alternative with every other alternative. Each pairing is evaluated against a criterion to determine which member of the pair has greater importance or performance, based on a scale of 1 to 9. A score of 1 means there is no difference between the alternatives for the criterion, while a score of 9 means that alternative A is absolutely better than alternative B when evaluated against the criterion. The scale is provided below:

- 1 – Equal
- 2 – Barely Better
- 3 – Weakly Better
- 4 – Moderately Better
- 5 – Definitely Better
- 6 – Strongly Better
- 7 – Very Strongly Better
- 8 – Critically Better
- 9 – Absolutely Better

In addition to being used to evaluate alternatives, this scoring method can be performed on sets of criteria to determine relative weighting, as shown in the Table 2.

Table 2: Pair-wise Comparisons of Criteria Criteria Set

- 1. Worker Safety and Health
- 2. Technical Maturity
- 3. Operations Factors
- 4. Versatility / Flexibility
- 5. Scalability to Stage III / Support of OU 7-13/14 RIFS
- 6. Production Rate
- 7. Speciation

Note: During evaluation, the team felt that Item 6 (Production Rate) was directly related to cost. We decided to eliminate the Production Rate from the Technical Evaluation.

	1	2	3	4	5	6	7
1	X	2 by 3	3 by 5	1 by 3	5 by 3	X	1 by 5
2		X	3 by 5	2 by 5	5 by 4	X	2 by 7
3			X	3 by 6	Equal	X	3 by 7
4				X	5 by 6	X	4 by 4
5					X	X	5 by 7
6						X	X
7							X

When using the pair-wise comparison method it is recommended that decision software be used to do the calculations.

Experience from the trade studies executed on this project favored using the pair-wise comparison when there were many subjective criteria, in that it was easier to maintain consistency when comparing two alternatives versus remembering previous scores when performing direct scoring.

As with other steps in this process, whenever decisions or judgements are made the rationale for the decision should be documented and communicated to stakeholders. Depending on the complexity of the trade study, frequent communication with stakeholders regarding study progress and decisions will help to maintain study focus, and help to manage stakeholder perceptions and expectations. Table 3 provides a simple, but effective example of documenting the rationale for weighing criteria.

Table 3: Rationale Documentation

1 vs. 2 - 2 by 3 because worker safety is a threshold, the premium paid for greater safety at the expense of getting a technically mature product adversely affects the ability to complete project goals.

1 vs. 3 - 3 by 5 because operations factors influence worker safety and health so much and the cost and schedule is so highly influenced by the operations factors that operations are a major driver.

Having selected the criteria for use in the trade study and having determined the criteria weighting, if any, before generating solution alternatives, maintains the integrity of the trade study process and in the end, provides for a better trade study solution.

Generating Solution Alternatives

For many, if not most engineers, generating solution alternatives is the “fun” part of their job. This is where creativity and innovative thinking are used. And in reality, when a design problem or issue is identified, engineering personnel are already thinking of potential solution alternatives, well before a trade study is commenced. Nevertheless, it is important to assemble criteria prior to brainstorming solution alternatives. Likewise, before beginning to look for alternatives, ensure that all involved understand the constraints that may be on the system. For example, in the Soils trade study the

alternatives needed to minimize perturbations to the existing design.

As with any brainstorming gathering, refrain from making any judgements on any idea during the meeting. Many times ideas generated from “out-of-the-box” thinking trigger thoughts for other personnel and create additional potential solutions. Use of a “trade tree” or “decision tree” can also help in generating multiple solutions and can be useful in identifying portions of the system that can be modified as part of a potential solution. Another consideration when generating alternatives is to look for solutions, which lend themselves to quantitative measures or simulation. List the alternatives and continue the process as long as fruitful discussion and ideas are being proposed. Always include ideas that customers and stakeholders suggest in the list of alternatives. They want to know that they are listened to, and feedback to them regarding their concepts can add credibility to the study and bring further buy-in from stakeholders.

Once a list of possible solutions has been created, group common alternatives and make an initial assessment to see if some alternatives can be eliminated in that they are duplicates. Table 4 provides a list of alternatives that were generated during the Soils trade study.

Table 4: Potential Solution Alternatives

<u>DQO-1 and DQO-2 (In-situ Undisturbed)</u> <u>Alternatives</u>	
1-1	Current Digface Monitor (DFM)
1-2	New DFM w/smaller head (like gamma-spec instrument)
1-3	Same as 1-2 except optimized for total number of scans
1-4	Stage I Sonic Driven Probes w/gamma-spec instrument
1-5	Passive-Active Neutron Detection
1-6	Baseline Biased Sampling Technique
1-7	Expanded Baseline Biased Sampling Technique
1-8	Expanded Baseline Biased Sampling Technique with “on-line” TRU Analysis
1-9	Ex-situ Post Retrieval (Generic category)
1-10	Stage I-like Coring Operation - biased technique using 3ft cores

Performing “Killer” Trades

The term “killer trades,” as might be expected, is used to “kill” or remove alternatives,

which do not meet fundamental criteria (e.g., threshold criteria). As mentioned above, threshold criteria are criteria that must be met for the alternative to be considered viable. This might include worker safety levels, radiation levels, alternative design capabilities or even alternative cost. For example, if an alternative is obviously prohibitive due to non-compliance with state or federal regulations, it should be eliminated from the potential alternatives list. If an alternative is removed from the list, it should be documented so that the rationale for removing an alternative is known. At later points in the project, questions may arise about certain design decisions, which can easily be answered by referring to the killer trade rationale within the trade study report. During the Soils trade study, killer trades were performed on the alternatives in Table 4 above. Table 5 illustrates the simple, but adequate notes that documented the rationale for why some alternatives were removed from the trade study.

Table 5: Rationale for “killer” trades

1-3	Killed due to being a duplicate of 1-2.
1-5	Killed due to high expense, high maintenance, more complex equipment, shielding requirements, does not provide any better data than gamma spectroscopy.
1-6	Left in the study for purposes of comparison, but should be killed because it does not meet statistical threshold criteria for this DQO.
1-7	Killed due to being a duplicate of 1-8.
1-10	Killed - If the aliquot size is 20 x 20 x 3 then an infinite number of samples are required. Even by reducing the aliquot size to 4x4x3 600 samples will be required. Even if this was allowed it would defeat the Stage II DQO #1 requirement for undisturbed soil. Post coring material handling, analysis, and cleanup will be extremely expensive and messy.

Evaluation of Technical and Cost Portions of the Trade Studies

Scoring the various alternatives should ideally be performed by an independent group or individual, which does not have knowledge of criteria weighting. This, again, reduces bias and preserves study integrity. Also, customers and stakeholders may want to see the evaluation performed in two separate groups, one assessing

the technical portions of the issue and one assessing the cost/schedule portion of the issue. Whether or not trade study technical and cost results are combined or not, the trade study performer should be prepared to show the details that make up the recommendation. That includes not only understanding the different pieces of analysis that made up the evaluation, but also any sensitivity analysis or adverse consequence analysis that were performed on the results.

There are various tools that can be used to assist the trade study team in their evaluation. These tools cover the entire range of tool complexities, from paper and pencil to spreadsheets to complete software packages tailored to perform trade studies. A Graded Approach should always be used to determine the appropriate tool.

Once the alternatives were reduced to a workable set in the Soils trade study, it was determined that some of the alternatives were not well suited to address all four soil populations / types (i.e., soil, stained soil, interstitial soil and probe disturbed soil). With this in mind, the remaining options were combined to make optimal use of each alternative. Table 6 contains these combined alternatives.

Table 6: Combined Alternatives

Alternative 1:	Current Digface Monitor (DFM) & New DFM w/smaller head (1-1 & 1-2)
Alternative 2:	Current Digface Monitor (DFM) & Expanded Baseline Biased Sampling Technique with "on-line" TRU Analysis (1-1 & 1-8)
Alternative 3*:	Baseline Biased Sampling Technique (1-6)
Alternative 4:	Expanded Baseline Biased Sampling Technique with "on-line" TRU Analysis (1-8)

* Included for comparison purpose. Does not meet DQO threshold requirements (reason for the trade study).

The above alternatives were then scored via a pair-wise comparison and the results are shown in Table 7.

Table 7: Scoring / Evaluation Results

Alternative 1:	.279
Alternative 2:	.218
Alternative 3:	.241
Alternative 4:	.261

A review of the scores shows that Alternatives 1, 3, and 4 performed similarly. At this point, a conclusion could be drawn that Alternative 1 is the best option, but given the closeness of the scores a sensitivity analysis was performed and a re-evaluation made of sub-criteria priority to see if a discriminating criterion could be found.

Pair-wise comparisons were made of the Pit Characterization sub-criteria, which previously had all been weighted equally. The resulting change in sub-criteria weight changed the total scores for each of the alternatives (see Table 8).

Table 8: Re-prioritized Criteria Results

Alternative 1:	.244
Alternative 2:	.237
Alternative 3:	.223
Alternative 4:	.296

It was found that rather than spreading the alternatives (i.e., identifying a clear "winner"), the re-prioritized ranking rearranged the alternatives. A closer examination of the individual criterion indicated that the "intrusiveness" criterion was significantly reduced in priority and therefore did not penalize Alternative 4 as much as when the criteria were equally weighted. Thus, it performed better than in the previous evaluation.

In this trade study it became evident that for this DQO the three new alternatives were approximately technically equivalent. When the alternatives were evaluated against the other DQO associated with the Soils trade study, a technically superior alternative was identified. It should be noted that finding technically equivalent solutions is not a bad result. If sensitivity analyses yield no significant differences other criterion or project needs can drive the final selection (e.g., cost).

When performing the cost portion of the Soils trade study, the criteria listed in Table 9 were used.

Table 9: Cost Criteria

Design costs (subsystem basis)
Capital costs (subsystem basis)
Start-up costs (procedures, training, testing, etc.)
Operating costs
- cost per sample
- processing time per sample
- consumables
- labor (sample management, data gathering, operations)

Schedule impact costs (costs of operating the facility beyond the baseline schedule)

Cost in CERCLA activities could have included penalties or fines levied due to missing enforceable milestones for alternatives that increase project schedules. When assessing alternative costs it is always best to have “cost actuals” available to provide credibility to assessment estimates. Often only part of the alternative’s costs can be based on actuals, which still provides better, more defensible estimates. Another approach that can be taken involves a “bottoms up” estimate of cost. This approach can be effective in providing solid cost estimates, which may be required by customers and/or stakeholders, but may prove to be an expensive approach. When it is not practical or possible to use actual costs, a comparative estimate of costs can be made. Large cost uncertainties are common in CERCLA projects, therefore comparative estimates may be the most practical approach. As with the rest of the trade study process, data used and assumptions made should be documented for each alternative. In the Soils trade study example, a comparative estimate was made for each alternative relative to the existing baseline design (i.e., delta costs from the baseline). Table 10 shows the cost evaluation results.

Table 10: Cost Evaluation Results

	Alt. 1	Alt. 2	Alt. 4
Design Costs	\$370K	\$380K	\$35K
Capital Costs	\$225K	\$200K	\$200K
Startup Costs	See Note		
Operating Costs	\$212K	\$675K	\$1,615K
Schedule Impact	\$0K	\$0K	\$1,238K
TOTAL COST	\$817K	\$1,245K	\$3,088K

Note: Startup Costs were not included because the delta cost between options was judged to be so small as to not the impact overall estimates.

From the table it is evident that Alternative 1 is the least expensive and that Alternative 4 is significantly more expensive than the others. For this trade study, it was concluded that Alternative 1 was the best solution for cost and technical complexity.

Summary

Trade studies can provide project managers with the information they need to make informed defensible decisions. Properly run, trade studies can be an effective tool, especially in the CERCLA environment where obtaining customer/stakeholder concurrence is essential for project progression and for decision making. Documented defensible decisions provide confidence to all parties involved in the project.

Effective trade studies performed on CERCLA projects balance risk, health & safety issues and regulatory compliance with cost and engineering viability. Criteria, alternatives and decisions are documented and clearly communicated to stakeholders such that concurrence can be achieved and project progress maintained. For the trade studies associated with this paper, obtaining customer/stakeholder concurrence along the way was essential to maintaining focus on a complex system and continued project progress. Not every complex trade study requires step by step concurrence. This will depend on the customer/stakeholders and contractors involved and the degree of oversight and involvement each desires.

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Acknowledgements

Work supported by the U.S. Department of Energy, Assistant Secretary for Environmental Management under DOE Idaho Operations Office, Contract DE-AC07-99ID13727

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